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Diesel Emission Control Strategies Available to the Underground Mining Industry

About the Study

This study provides an overview of emission control technologies for diesel engines, in general and in underground mine applications, based on published technical and scientific literature. The report also includes a brief introduction to diesel engines and emissions, as well as a concise summary of emission standards for onroad, nonroad, and mining diesel engines. It was prepared for DEEP by Dale McKinnon of ESI International and completed in February 1999.

Diesel Emission Control Technologies

Modern diesel engines have undergone a number of design changes in order to meet increasingly stringent environmental regulations. In particular, the U.S. requirements for onroad diesel engines in the 1990's have resulted in design changes to reduce both diesel particulate matter (DPM) and nitrogen oxides (NO_x) emissions. These changes include: improved fuel injection techniques, air management methods, combustion chamber design, and improved oil control. Many of these design changes have also been incorporated into off-road diesel engines and will continue to be applied as off-road diesel engine standards are tightened.

In-cylinder control methods can be supplemented by a number of exhaust gas aftertreatment technologies, which are available as retrofit devices for diesel engines operated in enclosed spaces or in other environmentally sensitive applications. The use of exhaust aftertreatment on new diesel engines is still limited, but will significantly increase over the next decade to satisfy coming environmental regulations. The following aftertreatment technologies are described in the report.

Diesel Oxidation Catalysts

Catalysts are substances that can accelerate chemical reactions without being changed or consumed. A catalytic converter consists of a stainless steel canister that typically contains a honeycomb-like structure called a substrate or catalyst support. The conversion of pollutants occurs when exhaust gases contact the catalyst, such as platinum or palladium, which is coated on the interior surfaces of the substrate. An oxidation catalyst transforms pollutants into less harmful gases by means of oxidation (combining them with oxygen molecules). In the case of diesel exhaust, the diesel oxidation catalyst (DOC) oxidizes carbon monoxide (CO) and hydrocarbons (HC). The hydrocarbon activity of the DOC extends to such materials as PAHs, and the soluble organic fraction (SOF) of diesel particulates in general. Through this effect, DOCs can reduce DPM emissions.

The sulfur content of diesel fuel is critical to applying catalyst technology. Catalysts used to oxidize the SOF can also oxidize sulfur dioxide to form sulfate particulates (sulfuric acid), which are measured as part of the particulate matter. Through this effect, DOCs may increase the total DPM emission. Active DOCs may also oxidize nitric oxide (NO) to nitrogen dioxide (NO_2), which has much lower permissible exposure limits. Catalyst formulations have been developed which selectively oxidize SOF while minimizing oxidation of sulfur dioxide or nitric oxide. However, fuels with lower sulfur content always increase the effectiveness of oxidation catalyst technology.

DOCs are a well established commercial technology. From 1994 to 1998, over 1.5 million oxidation catalysts were installed on new onroad heavy-duty diesel engines in the U.S. and over 6 million passenger cars were equipped with oxidation catalysts in Europe.

Numerous converters have been also retrofitted to nonroad engines.

Diesel Particulate Filters

The diesel particulate filter (DPF) consists of a filter designed to collect the DPM emissions in the exhaust stream of a diesel vehicle, while allowing the exhaust gases to pass through the system. A complete DPF system consists of the filter and the means to facilitate filter *regeneration*, i.e., the disposal of the accumulated soot. The most popular form of regeneration is thermal regeneration, where the soot is oxidized ("burned") to gaseous products. However, in nonroad applications, disposable filter systems are also used. The disposable filter is sized to collect DPM over a certain period of operation. When filled with soot, it is removed from vehicle and disposed of.

The most common filter materials include a porous ceramic materials called *cordierite* and *silicon carbide* (SiC). The DPF substrates are honeycombs similar to catalytic converters, but with alternate channel ends plugged to force gas flow through their porous walls.

Some of the common regeneration methods include:

- Using a catalyst-coated filter. The application of a catalytic coating to the surface of the filter reduces the temperature needed for oxidation ("burn off") of DPM;
- Using fuel-born catalysts to reduce the temperature required for the ignition of the accumulated material;
- Using fuel burners, electrical heaters, or the combustion of atomized fuel by catalyst to heat the incoming exhaust gas to a temperature sufficient to oxidize the particulate;

Similar to DOCs, filter systems that utilize catalysts for regeneration may *increase* emissions of sulfate particulates (sulfuric acid) and NO_2.

Filters have been commercially retrofitted to nonroad equipment since 1986. Currently, over 2,500 systems are in operation worldwide with some of the systems having operated for over 15,000 hours or over 5 years. Improvements in filter materials result in increased durability of DPF systems.

Selective Catalytic Reduction (SCR)

The SCR technology has been developed for NO_x control in stationary sources, including stationary diesel engines. A chemical agent (ammonia, urea) injected upstream of the SCR catalyst, reacts with NO_x, reducing it to harmless products.

SCR systems are currently being developed for NO_x control from mobile sources.

Emerging NOx Control Technologies

Several emerging technologies for diesel NO_x control are described in the report, including lean NO_x catalysts, NO_x adsorbers, and plasma-assisted catalysts.

Effectiveness of Technologies

Approximate emission reduction potential of various technologies is listed in the table.

Technology	Control Capability, %			
	CO	HC	NOx	DPM
Diesel oxidation catalyst	>90	>90	n/a	>25
Diesel particulate filter	n/a	n/a	n/a	>90
SCR catalyst	>50	>70	80	>30

Control Technologies for Underground Mines

Technologies that have been proven and are currently available for underground mining include diesel oxidation catalysts and particulate filters. To reduce underground miners' exposure to diesel emissions, the mining industry can use strategies that include exhaust emission control technology, "clean" engine technology, and higher fuel quality.

Cost of Diesel Emission Controls

Approximate costs of aftertreatment devices are estimated as follows (US $ per 1 hp of the engine rated power):

- Diesel Oxidation Catalysts 8 – 12 $/hp
- Diesel Particulate Filters 30 – 50 $/hp
- Selective Catalytic Reduction ~50 $/hp